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Mechanisms for the Onset and Evolution of North American Monsoon

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ABSTRACT

The North American Monsoon (NAM) is a seasonal shift in the large-scale circulation that supplies summertime precipitation in northwestern Mexico and US southwest. An understanding of the NAM's major governing processes is necessary to improve global and regional climate modeling, including the NAM's remote impacts on the summer circulation, precipitation and drought over North America.

In this study, we suggest a partial mechanistic understanding of the NAM. In the local scale, this mechanism helps to explain how the low-level moisture from the Gulf of California (GC) fuels the NAM rainfall. The proposed hypothesis is supported by satellite observations, ship soundings launched over the GC, and regional model (WRF) simulations.

North American Monsoon Experiment (NAME) field campaign in summer 2004 provides unique enhanced observational data such as multi network composite rainfall and Multiplatform-Merged (MPM) SST for evaluation of the model. WRF simulations show that warmer GC SSTs tend to enhance low-level moisture during this period and as a result more precipitation occurs over the foothills of Sierra Madre Occidental (SMO) and over US southwest. However, predicted inversions are stronger than those observed. This discrepancy may represent an opportunity to improve WRF performance over North America during summer.

1. Introduction

The North American Monsoon (NAM) provides about 60% - 80%, 45% and 35% of the annual precipitation for northwestern Mexico, New Mexico (NM) and Arizona (AZ), respectively (Douglas *et al.* 1993; Higgins *et al.* 1999). An intercomparison of regional climate models by Mearns *et al.* (2012) has shown that summer precipitation prediction over North America is the poorest in the NAM region. NAM rainfall is relevant to the amplification and northward shift of the upper level anticyclone over the southwestern US, called the monsoon anticyclone or monsoon high (Carleton *et al.* 1990; Higgins *et al.* 1999).

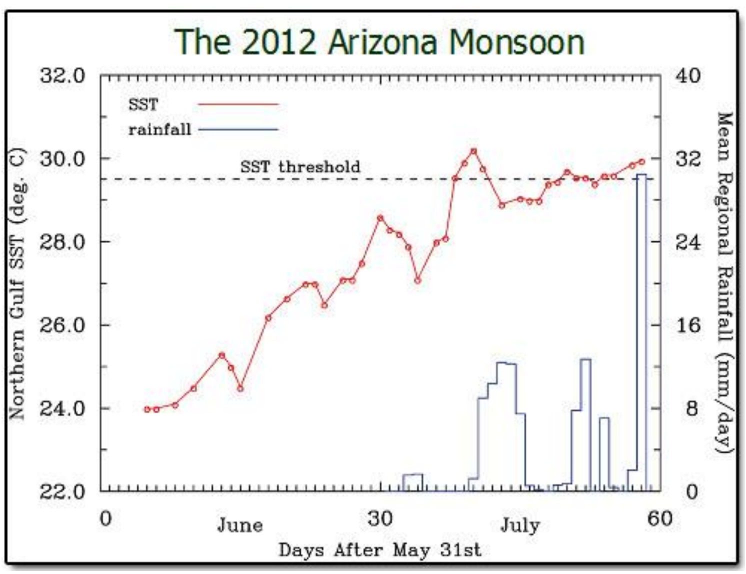

Fig. 1 Temporal evolution of Arizona rainfall rates and N. GC SST in June and July 2012. Similar results were seen in Mitchell *et al*. (2012) for five June–August seasons.

Several studies investigated the importance of GC SSTs on NAM rainfall. An empirical study of six monsoon seasons by Mitchell *et al.* (2002) indicated that no monsoon precipitation was observed in the

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NAM region when GC SSTs did not exceed 26°C. They also showed that 75% of June-August precipitation in Arizona-New Mexico region occurred 0-7 days after the northern GC SSTs exceeded 29.5°C.

Although various observational and modeling studies showed some characteristics of the NAM, a mechanistic understanding of the NAM is still elusive. In this study, we offer a partial mechanism that addresses mesoscale processes. Section 2 discusses the relationship between GC SSTs, inversion cap and relative humidity based on both observations and numerical simulations. Conclusions are presented in section 3.

2. Results

In this research, we utilized sea surface temperature (SST) and rainfall amount observed from satellite, temperature and moisture profiles from ship soundings launched over the GC, and regional scale model simulation over the NAM region by WRF.

Following Mitchell *et al.* (2002), we have analyzed three other monsoon seasons at higher resolution regarding SST and AZ rainfall amounts, resulting in similar findings. Figure 1 shows the most recent example. All these findings indicate rainfall begins after the northern GC SST exceeding a threshold of 29.5°C. The mechanism for this relates to the marine boundary layer (MBL) over the northern GC (Figure 2). For SSTs < 29°C, the air over GC is capped by a strong inversion of ~ 50-200 m above the surface, restricting moisture to MBL in GC. The inversion generally disappears once SSTs exceed 29°C, allowing MBL moisture to mix with air in free troposphere. This results in a deep, moist layer that can be advected inland to produce thunderstorms.

A set of carefully designed simulations using WRF is conducted to investigate the dependence of NAM precipitation and onset on SSTs in the GC. WRF is able to simulate low level jet (LLJ) parallel to the GC axis during the 2004 monsoon onset. In agreement with observations, WRF simulations show that warmer GC SSTs tend to weaken the inversion that caps the GC MBL and increase low-level moisture

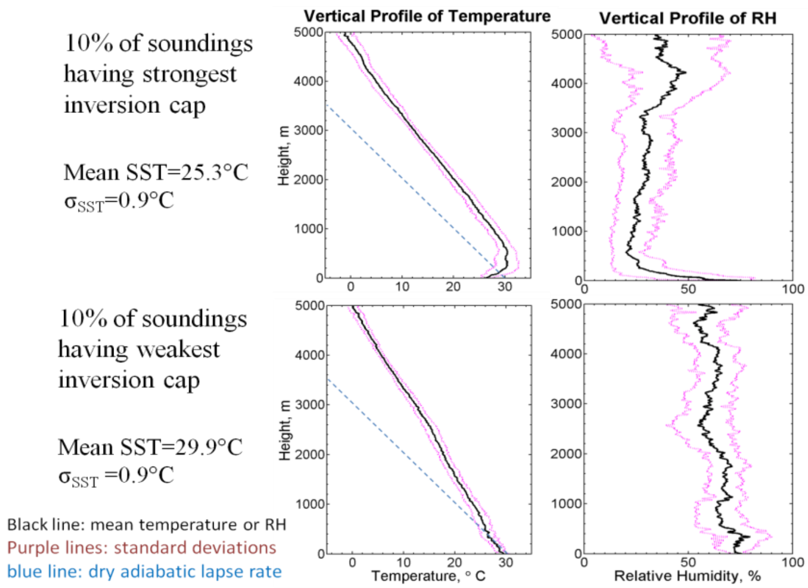

Fig. 2 Vertical profile of temperature (left panels) and relative humidity (RH) (right panels) for 10% of soundings having the strongest inversion cap over GC (upper panels) and for 10% of data having the weakest inversion cap over GC (lower panels) based on RV balloon sounding.

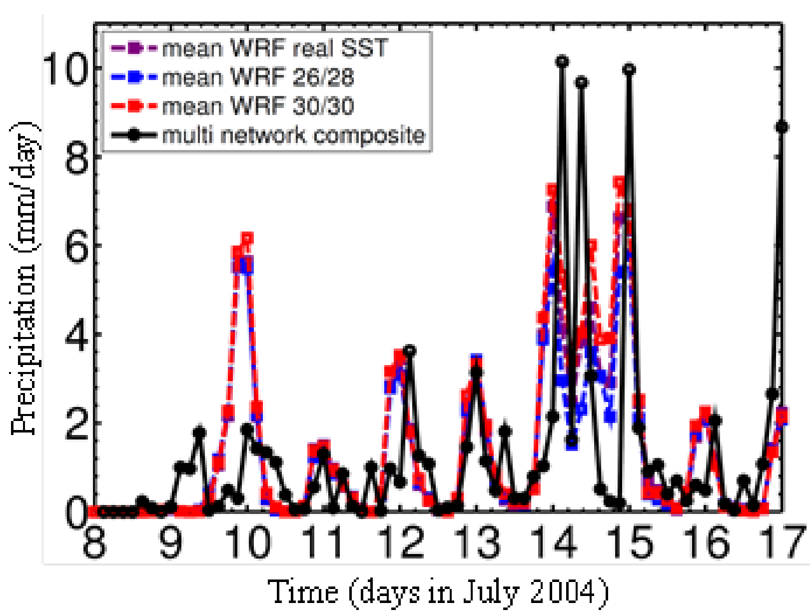

Fig. 3 Time series of precipitation rate in Arizona region for both observations and WRF simulations from 8 to 17 July 2004.

during this period. This leads to the rainfall enhancement in AZ region (Figure 3). However, WRF simulates a stronger inversion compared to observational soundings and as a result, moisture profiles in WRF simulations are drier compared to observational soundings (figure not shown). This might explain the underestimation of rainfall in WRF simulations compared to observations as shown in figure 3.

3. Conclusions

We suggest a mechanism to physically understand key processes governing NAM. The mechanism at the local scale is related to the MBL over northern GC. The strong low-level inversion, capping the top of shallow MBL, weakens with increasing SST and generally disappears once SSTs exceed 29°C, which allows the trapped MBL moisture to mix with free tropospheric air. This leads to a deep, moist, well-mixed layer that can be transported inland to form thunderstorms. WRF simulations generally agree with the observations, however overestimate the inversion and underestimate the moisture profile and rainfall. This discrepancy may represent an opportunity to improve WRF performance during summer over North America.

References

Carleton, A.M., D.A. Carpenter, and P.J. Wesser, 1990: Mechanisms of interannual variability of the southwest United States summer rainfall maximum. *J. Climate*, **3,** 999–1015.

Douglas, M.W., R.A. Madox, and K. Howard, 1993: The Mexican monsoon. *J. Climate,* **6,** 1665-1677.

Higgins, R.W., Y. Chen, and A.V. Douglas, 1999: Interannual variability of the North American warm season precipitation regime. *J. Climate,* **12,** 653-680.

Mearns, L.O., and Coauthors, 2012: The North American Regional Climate Change Assessment Program: Overview of Phase I Results. *Bull. Amer. Meteor. Soc.*, **93**, 1337–1362.

Mitchell, D.L., D.C. Ivanova, R. Rabin, T. J. Brown, and K. Redmond, 2002: Gulf of California sea surface temperatures and the North American monsoon: Mechanistic implications from observations. *J. Climate,* **15**, 2261-2281.